SUITT, CONSTANCE DePEW. The Visually Evoked Cortical Potential: Stimulus Effects and Interactions. (1971)
Directed by: Dr. Robert G. Eason. Pp. 52.

The purpose of this investigation was to obtain parametric data on the effects and interactions of stimulus variables (intensity and size), retinal locus of stimulation and background adaptation level on the visually evoked cortical potential.

The subjects were graduate students and faculty with no gross visual defects. The potential was evoked by white light flashes and averaged with a Mnemotron CAT. Three amplitude components of the evoked potential were measured for each of the subjects, over four replications, averaged, and an analysis of variance was performed on the data.

The amplitude of the evoked potential was found to vary significantly as a function of site of stimulation ($p < .01$), intensity of the stimulus ($p < .01$), and size of the stimulus ($p < .05$). The background variable was not found to effect a significant change. Three significant first-order interactions were found: background by site ($p < .05$), background by size ($p < .01$), and site by size ($p < .05$).

An important implication of the results is that consideration should be given to the magnitude of the physical parameters of the visual stimulus, and to their interactions, when interpreting the results of experiments dealing with relationships between visually evoked potentials and behavioral variables.

THE VISUALLY EVOKED CORTICAL POTENTIAL: STIMULUS EFFECTS AND INTERACTIONS

by

Constance DePew Suitt

A Thesis Submitted to
the Faculty of the Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Master of Arts

Greensboro
1971

Approved by

Robert H. Eaton
Thesis Adviser

This thesis has been approved by the following committee of the Faculty of the Graduate School at The University of North Carolina at Greensboro.

Thesis adviser Robert G Eason

Oral Examination Committee Members M. Russell Waites

Ernest D Lumsden Jr

April 14, 1971
Date of Examination

ACKNOWLEDGEMENTS

Appreciation is expressed to Dr. Ernest Lumsden for serving as a committee member and to Dr. Russell Harter for his aid as a committee member as well as his technical assistance in data collection.

Dr. Robert Eason in sincerely thanked for his persistence and patience in serving as advisor and consultant.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The advent of averaging techniques to determine evoked cortical responses has brought about an abundance of investigations concerning the electrophysiology of vision, in addition to other sensory modalities. Studies in visual evoked cortical potentials deal mostly with questions related to established theories and laws of vision. These are presented as a prologue to a review of the experimental literature.

Nature of the Retina

Anatomical studies have described the human eye in terms of a light sensitive duality of the retina. The first proposal of this duplicity was in 1866, when it was observed that the retina of diurnal fowl contained a great majority of cones in contrast to the nocturnal, which was mostly composed of rods. It was concluded that these were the receptors of day and night vision, respectively. LeGrand (1957) discusses this concept of the duality of the retina, describing the retinae as being interlaced with one another: the day retina of color vision, adapting to darkness quickly but minimally; the night retina of colorless vision, sensitizing to darkness slowly and over a wide range as darkness becomes

longer. In the fovea, the day retina is present; in the remainder of the retina (periphery), the two retinae exist side by side, with the night retina predominating more and more with increasing eccentricity. Thus, the receptors for photopic vision are cones, and are functional during high levels of luminance. As luminance is diminished (dark adaptation), vision becomes more scotopic and the function of the more sensitive rods comes into play. Boynton (1968) asserts that part of the reason for the drop in threshold during dark adaptation is related to the increase in sensitivity of each relevant receptor and, in addition, related to the increase in the size of the summation area.

Early anatomical work indicates that the visual projection on both the cortex and superior colliculus is a singularly precise map of the retina. This has been investigated by the electrical technique of evoked potentials.

The Evoked Potential

A general definition of an evoked potential is offered by Chang (1959) as the detectable electrical change in any part of the brain in response to deliberate stimulation of a peripheral sense organ, a sensory nerve, a point on the sensory pathway or any related structure of the sensory system. Katzman (1964) has reported that the latency and waveform of a visually evoked response recorded from the scalp is similar to that recorded from the brains of experimental animals. The distribution of responses on the scalp corresponds closely

with potentials generated by the visual cortex. It is the general consensus among investigators that the evoked potential differs from spontaneous electrical changes in the following ways: (a) The evoked potential consistently bears a definite temporal relationship with the onset of the stimulus. It has a definite latent period determined by the conduction distance between the point of stimulation and the point of recording, the synaptic delay and the number of synapses involved. Within a given system, the latency is generally fixed and consistent under similar experimental conditions. (b) It has a definite pattern of response characteristic of a specific system which is more or less predictable and reproducible under similar circumstances. (c) It usually appears in a circumscribed area of the central nervous system where the active tissue is located. (Chang, 1959.)

The technique of averaging used in evoked potential research is based on two assumptions (Dawson, 1954). First, the ongoing EEG activity and other electrophysiological "noise" will have random polarities and amplitudes if short samples are taken over a large number of trials. If these samples are added together, the random nature of the noise will result in an algebraic sum of zero. The second assumption is that the response of the brain evoked by a sensory stimulus will be time-locked to that stimulus and each evoked response should have a similar waveform (be in phase) to every other response evoked by an identical stimulus.

Therefore, if a series of identical stimuli is presented and the EEG is sampled immediately following the presentation of each stimulus, the algebraic summation of these samples should result in the amplitude of the evoked response increasing as a function of the number of samples, and the amplitude of the ongoing EEG activity decreasing as a function of the number of samples. Thus, there is the situation of the signal increasing and the noise decreasing as a function of the number of stimuli presented. It holds then that if sufficient stimuli are presented, the signal-to-noise ratio will eventually permit detection of the signal.

Electrode placement. Gastaut, Regis, Lyagoubi, Mano, and Simon (1967) investigated electrode placement to determine whether or not certain regions of the brain responded selectively to a given sensory stimulus or whether this response could be distinguished from that obtained after activation of another sensory system. Potentials were explored from the view of morphology and latency, and it was concluded that visually evoked cortical potentials were recorded with maximum amplitude and precision from the inion or within a semi-circle of a 30-cm. radius centered on the inion. Kitajima (1967), recording from two electrodes placed bilaterally from the inion and two others in parietal areas found that, in spite of individual variations, responses were more predominant in the occipital area, than in the parieto-occipital in terms of size and phase.

Reliability of response. With constant conditions, Cobb and Dawson (1960) found the repeatability of the form of the evoked potential response was high over 20-minute periods. Furthermore, over several months, the repeatability was still found, despite the appearance of variation in the relative size of some of the components. In a subsequent study to determine the measure of reliability of averaged evoked potentials, Dustman and Beck (1963) analyzed data indicating that those components of an individual's averaged evoked potential occurring in the first 300 msec. were highly reliable over intervals separated by a week or longer, with a reliable intra-individual correlation. It was concluded that evoked responses of different individuals tended to be unique. This conclusion is further supported by a study of response variability (Werre and Smith, 1964) as a function of time, area, and subjects wherein it was reported that there was a recognizable similarity among the visual responses for all subjects, but conspicuous departures from the general outline of the response in individual cases. Differences between subjects were outstanding, and less salient were differences in an individual when studied repeatedly. It is proposed that in addition to the potential changes induced by visual stimulation, there is an existing "spontaneous" cerebral activity which is more or less specific for each individual. Vaughan (1966), in an intensity study, found the measurement of the visually evoked response to be

fairly reliable for each subject, showing substantial inter-individual variation. Ciganek (1969), while studying single responses within the evoked potential, reported that amplitude variability was high, due mainly to background activity. The variability of the evoked potential was negligible. Approximately 50 per cent of the subjects showed a decrease of variability about 80 msec. after stimulation, due to blocking of background activity. An average group response supported the existence of a standard, although inter-individually very variable, human visually evoked potential.

Components. An investigation by Vanzulli, Bogacz, Handler, and Garcia-Austt (1960) of the photic response reported that the initial visually evoked response component is a succession of waves of varying amplitude, duration, and form, followed in an inconsistent fashion by a monomorphous afterdischarge related to synchronization of background activity. Perry and Childers (1969) report that a potential, when evoked by stimuli presented at a slow rate, is a complex polyphasic wave of positive and negative components, the number of deflections being a function of the experimental conditions and subjects. Vanzulli et al. (1960) also noted that during wakefulness, the initial component varied between subjects, with the most elemental pattern being a sharp positive wave followed by a smooth negative one. The most complex types consisted of increasingly more numerous successions of these positive-negative potentials.

Based on experiments of sensory thresholds and subthresholds, Shagass and Schwartz (1961) found the same components as Vanzulli et al. (1960). They noted also that the secondary waves seemed to be influenced by psychological factors, as was reported by Werre and Smith (1964). Shagass and Schwartz indicate that the evoked potential may be an objective sign of sensory awareness. Ciganek (1961) divides the normal evoked potential into two constituents: the primary response having the character of a specific response, and the secondary response produced by nonspecific perhaps diffuse pathways. Van der Tweel and Spekreijse (1966), in a literature study, reveal that attention or probably relevance of the stimulus in one way or another tends to increase the amplitude of the evoked potential. Artseulova and Ivanitskii (1967) in a correlational study of the relationship between parameters of evoked potentials and background bioelectric activity found only part of the components of the evoked potential definitely correlated with background activity. The authors assert that these components do not depend directly on the character of the cortico-reticular relation, but more so on the specific system stimulated.

White and Eason (1966) view the constituents of the evoked potential differently with regard to their production. They concluded that there were a number of component responses, each being related to some aspect of the stimulus situation. They further concluded that the evoked response

pattern which was produced by high intensity level ganzfeld stimulation produces a composite of these various responses. In a later study, Eason and White (1967) propose that the averaged evoked cortical response be considered an objective index of visual threshold, in accord with previous studies.

Intensity

Since subjective brightness and perceptual latency are inversely proportional in psychophysiological experiments, cerebral events associated with appreciation of brightness may be expected to exhibit a similar relation between stimulus intensity and latency. Vaughan and Hull (1965) considered the possibility that the latency of the visually evoked response was an objective index of brightness perception. The authors found that as stimulus intensity increased (from 2.5×10^{-2} mL. to 2.5×10^{7} mL.) the visually evoked response underwent a regular transformation of latency, amplitude, and wave configuration. The amplitude of the various components reached a maximum at intermediate intensity levels and decreased somewhat at higher luminances. Latency was a monotonic decreasing function of stimulus intensity. When all identifiable components of the visually evoked response were plotted as a function of stimulus intensity, it was found that the interval between peaks remained constant, making it impossible to identify any specific portion of the evoked potential as uniquely related to perception of brightness solely

on the basis of latency. Similar findings by Vanzulli et al. (1960) indicate that changes in intensity produced changes in latency, amplitude, and form. Latency decreased steadily with an increase in intensity. Amplitude augmented in step with intensity, though not in proportion to its logarithm. In some cases, amplitude was lower with maximal intensity than with sub-maximal. This decrease of amplitude in cases of high intensity suggests to the authors the existence of an inhibitory mechanism. The rise of amplitude and appearance of shorter latency components with increases in intensity presupposes that in the presence of intense stimuli the brain receives a larger amount of information in a shorter time than with low intensity. This increase in intensity provokes enhancement of awareness and hence sensory receptivity. Creutzfeldt and Kuhnt (1967) and Wicke, Donchin, and Lindsley (1964) conclude that waveform and amplitude of the evoked potential are systematically related to luminance duration and therefore to the apparent brightness of the eliciting flash.

Tepas and Armington (1962), using a 1 Hz. flickering white light over a range of 8 log units of neutral density filters, found that the amplitude of the evoked potential increased with increased luminance, but further increases in luminance tended for the amplitude to diminish. The data suggest that the relationship between amplitude of the evoked potential and stimulus luminance was not necessarily a monotonic one. The peak-to-peak amplitude increased with an increase of luminance for two components. A double-log plot of

these peak-to-peak amplitudes against luminance showed that relations between log luminance and log amplitude could be described as roughly linear for filter range 12 to 3. Beyond this, at the highest luminance values, the relation no longer held, as the major component broke into sub-components. Dill, Vallecalle, and Verzeano (1968) and Perry and Childers (1969) found that in general, increasing intensity of stimulation produces evoked responses which are characterized by a greater complexity, greater amplitude, and shorter latencies. As other investigators have reported, extremely intense stimuli produced a great reduction in response size. In a study of the relationship between intensity and evoked potential, Montagu (1967) reported that during stimulation at the lowest rate (6 Hz.) and at higher rates (16-30 Hz.), the fundamental response increased with each increase in intensity. The relation was approximately linear when the log response was plotted against intensity on a linear scale. During stimulation at the intermediate rates (8-12 Hz.) the fundamental response increased with the intensity only up to a certain point. Further increases in intensity resulted in a decrease of response. Kitajima (1967) reported that typically, the maximal amplitude of the response had approximately linear relationships to the log amount of the relative strength of the stimulus.

Investigating flash and scan stimulation, Dawson, Perry, and Childers (1968) report that the magnitude of the evoked

potential is directly related to the amount of light admitted to the retina, whether the stimulus is diffuse or scans the retinal fields. When a luminous spot, moving at 21 or 45 cm./sec., respectively, was viewed, the evoked potential magnitude exceeded that produced by a stationary diffuse flash, although the brightness of the stationary flash was greater by a factor of 15.

Cobb and Dawson (1960) report that a reduction in the apparent brightness of the flash stimulus leads to a reduction in the size of the occipital response and an increase in its latency. Buchsbaum and Silverman (1968) hypothesized that an individual whose kinesthetic figural aftereffect (KFA) scores indicated a tendency to reduce perceived intensity of strong stimuli would show comparable response tendencies in evoked cortical potentials. There was a significant correlation between response latency and amplitude measure and KFA values in both groups (normal and nonparanoid schizophrenics). In direct contrast to normal subjects, the schizophrenics evidenced increasingly longer reaction times in response to visual stimuli as the stimulus intensity increased. Increases in the intensity of external stimuli associated with reduction in experienced intensity of input evidenced a slowing of motor reaction to high intensity stimuli. Eason, Oden, and White (1967), in a study of reaction time, found similar relationships between motor reaction and the amplitude and latency for visually evoked potentials. In that same study,

attention proved to be effective in altering the magnitude of the evoked potential. In accord with this is a study by Kopell, Wittner, and Warrick (1969) in which it was found that the amplitude of the evoked potential produced by stimuli not sensitive to attention was proportional to the intensity of the stimulus. White and Eason (1966) report that, in regard to minimal stimulation, if the stimulus situation is perceived by the subject an evoked response will be obtained.

Site

Analysis of the light-evoked visual response in man indicates that although photopic (cone) and scotopic (rod) systems contribute to responses, the photopic appears dominant. This has been demonstrated by the photopic character of the spectral sensitivity curve derived from measurement of the evoked response amplitude (Armington, 1966) and the behavior of the response during dark adaptation (Perry and Copenhaver, 1966).

Boynton and Riggs (1951) indicated that it was possible to obtain sizable responses from stimuli calculated to illuminate only the fovea or blind spot. The foveal response was slightly, but significantly, smaller than either the blind spot or the peripheral responses, which were indistinguishable from each other. These results led the authors to conclude that the retinal response is primarily aroused by stray light rather than by focal illumination. They hypothesized that

the effect of increasing either stimulus area or intensity, within the limits of their experiment, was to increase the illumination of the vast "nonfocal" area, and that it was this nonfocal illumination which produced nearly all the response.

DeVoe, Ripps, and Vaughan (1968), using 2° and 5° stimulation on the temporal retina, found that subjectively the visual sensitivity increased as the stimulus spot moved outside the central retina, due to stimulation of an increasing number of scotopic receptors. The sensitivity measures by the evoked response dropped precipitously at only 2°. The authors did not extrapolate to 5°. Eason et al. (1967b), using sites of stimulation along the horizontal meridian of the temporal retina of the right eye, 5°-50°, report that, with red and blue light, the earliest deflections were of relatively greater magnitude when the retina was stimulated at or near the fovea than when stimulated more peripherally. In contrast, later deflections became more accentuated as the eye was stimulated more peripherally.

In a recent investigation Eason and Dudley (1971) report that the retinal locus of the stimulus had a significant effect, with the largest responses being evoked by foveal stimulation and the smallest by the most peripheral (40°) locus of stimulation. In the same study, a significant interaction was found between size of the stimulus and locus of stimulation. The effect of size on the amplitude of major

deflections depended significantly on the site of retinal stimulation.

Most reports are in agreement that there is a decrement in response size as the stimulus is moved peripherally away from the fovea. In a gross way, the evoked response decrement with peripheral stimulation follows the cone receptor density distribution of the retina. Amplitude has been found to provide an evoked response correlate to the Stiles-Crawford effect. Light entering the pupil at an oblique angle has been shown to reduce the evoked potential size as it reduced apparent brightness (Perry and Childers, 1969). DeVoe et al. (1968) proposed the Stiles-Crawford effect in reporting that rays were maximally effective when entering near the pupillary center, the efficiency decreasing with increasing displacement from the center. Pirenne (1967), in a discussion of the Stiles-Crawford effect, states that the intensity of the stimulus may have to be increased threefold to make it appear as bright for peripheral as for central entry through the pupil. The visual efficiency of a narrow pencil of light which is made to explore the whole pupil is found to be greatest near the center of the pupil and to increase progressively for positions increasingly distant from the center. In the rod-free fovea, such variation of efficiency with pupil entry is always observed, varying in extent according to the experimental conditions. In the periphery this does not always occur. It will occur when the eye is light-adapted; but not during dark adaptation with dim light sources emitting short

or medium wavelengths. Retinal cones possess this directional sensitivity to a high degree. The rods are much less directional, at angles of incidence accessible through the pupil. Light entering near the edges of the pupil is considerably less effective than light entering through the middle of the pupil. The physiological efficiency of the light stimulus reaching a given point of the retina is not dependent simply on the total amount of light which, having entered the eye through the pupil, converged upon this point of the retina.

Size

DeVoe et al. (1968) reported on an increase in response amplitude and reduction in latency as the diameter of the test field was increased. The evoked response results were relatively the same as found subjectively. As area increased, threshold luminance decreased, approaching asymptotically some limiting value, i.e., threshold eventually became independent of stimulus size. Graham, Brown, and Mote (1939) state that an inverse relation exists between size of retinal image and intensity of light required to evoke a threshold response. Intensity thresholds followed a typical course with an increase in area in both the fovea and the periphery. The peripheral eccentricity of regard was at such an angle that even the largest areas stimulated were beyond the limits of the fovea. In both regions, the intensity threshold was high for small areas. As area was increased, the threshold increased until, in large areas, it approached

a final, limiting value. In the fovea, the decrease of threshold with an increase in area took place within the confines of a stimulus diameter of approximately 1°. In the periphery, the final level appeared at a diameter of 10°. Copenhaver, Beinhocker, and Perry (1964) found that a change in stimulus size (2.5, 5, and 10°) had little influence on the size of the evoked potential. Full field stimulation with background illumination turned off resulted in an evoked potential almost identical in size to that obtained from stimulating with a 2.5° stimulus and background illumination of 8 mL. Similar findings by Eason and Dudley (1971) cite an increasing-decreasing relationship between amplitude of late components and stimulus size during peripheral stimulation which is not evidenced during foveal stimulation with varying sizes.

Background

Hecht (1921) reports that the fovea is essentially an instrument for bright vision. General dark adaptation is a phenomenon of dim vision. When the light-adapted eye is removed to darkness, the pupil dilates and the retina increases in sensitivity. Most adaptation occurs during the first 30 seconds, with the process practically ceasing after 10 minutes. White and Eason (1966) state that an increase in the overall magnitude of response from near-threshold conditions to high contrast conditions agreed with the corresponding changes in the perceived flash intensity. The authors

consider photopic and scotopic vision as two separate submodalities in view of the different time courses of their neural activity following stimulation. Scotopic neural activity was observed as occurring later than photopic-related activity. Three positive components of the evoked potential were hypothesized. One, related to scotopic visual activity, tended to be present only under lower background conditions. Two others appeared to be photopic, with each related to different types of photopic activities. One remained constant over the entire range of stimulus intensities and background levels in terms of latency and varied directly in terms of amplitude with stimulus intensity for any background level. In the other, it was found that the peak latency decreased significantly under higher background intensities, and varied in amplitude depending on those intensities.

Perry and Childers (1969) present a discussion of two types of receptors existing in the retina which respond differently to different stimulation. What might be called the maximum efficiency of each is dependent upon the level of adaptation produced by the preceding stimulation. The rods respond optimally when prior stimulation has been dim or no light (dark adaptation or scotopic function) and the cones respond optimally when prior stimulation has been bright light (light adaptation or photopic function). Both receptors initiate retinal activity. With the rods outnumbering cones 17 to 1, the cone/rod proportion favors rods at the retinal

recording level. This is not maintained when recording at the cortex because many multiple rods converge to single fibers in the optic tract and many single cones are represented by a single fiber. Thus, the visually evoked potential is considered much more representative of cone-initiated activity. The effect of dark adaptation upon the evoked response was reported maximal by Perry and Childers (1969) at a stimulus rate of 1 flash per sec. In the opinion of the authors, the greater foveal (cone) representation at the cortex probably provides the greatest impediment to observing scotopic (rod) function in the evoked response.

Once the eye becomes dark-adapted, this adaptation situation appears to be stable. The achievement of a scotopic level of adaptation with a relatively bright flickering light, even if the stimulus is well within photopic range (as 100 flashes at 4 flashes per sec.), introduces only 0.5 log units of light adaptation (Perry & Childers, 1969). After 40 minutes of dark adaptation, then, typical stimulation would not raise the total adaptation level significantly toward the photopic range.

Purpose

The investigations reviewed above indicate that properties of the visual stimulus (size and intensity), site of retinal stimulation, and background luminance level all have a systematic and consistent effect on the magnitude of the

visually evoked potential. Thus, there is considerable information available as to the relation between evoked responses and each of the variables considered singly. However, the literature reveals little information as to how these variables interact in their effect on the evoked response. Few investigations have varied two or more stimulus parameters systematically, and too often, during intensity studies for example, other parameters go uncontrolled or sometimes unreported. No studies were encountered which varied all four parameters (size, intensity, site, and background) to determine if, and/or to what extent, they interacted in effecting changes on the amplitude of the evoked potential.

In response to this dearth of information, the present investigation manipulated all four stimulus variables. The primary purpose of the experiment was to obtain systematic, parametric data concerning the main effects of each variable on the visually evoked cortical potential, and especially to ascertain the extent of the interaction effects of the four variables on the evoked response.

METHOD

Subjects

Three female graduate students, one male graduate student, and two male faculty members from the University of North Carolina at Greensboro served as subjects (Ss). All were experienced subjects in psychological experiments, but two of the female Ss were naive in physiological experiments of this kind. No gross visual defects existed in any of the Ss, and those requiring correction used their prescription lenses.

Experimental Design

The object of this experiment was to obtain parametric data on the effects of variation in the physical stimulus on the visually evoked cortical potential. The following independent variables were manipulated: background intensity (light and dark), site of retinal stimulation (foveal and peripheral), stimulus intensity (bright and dim), and size of stimulus (small and large).

The experiment consisted of two phases with each subject serving in both Phase I and Phase II. Phase I consisted of four sessions, each containing four trials (runs), wherein S was exposed to the smaller-sized stimulus (a 1^{o} spot of light). Depending on the condition being run, each session lasted from one hour to one hour forty-five minutes. Background level, stimulus intensity, and site of retinal stimulation were systematically varied, size being held constant.

The two background levels will be referred to as the "light" and "dark" conditions. The "light" condition was generated by the combined illumination of a 120-volt overhead incandescent light placed approximately three feet above S's head and standard neon ceiling lights located in the room. The luminance of the stimulus screen was 10 mL., and S was light-adapted to this level prior to each run. The "dark" condition contained no available light source, and the luminance level of the viewing screen under these conditions was less than 0.01 mL. S was dark-adapted to this low level of illumination prior to each run. The intensity of the stimulus flash was controlled by passing the light flashes produced by a Grass photostimulator set at I = 16 through Kodak Wratten filters. During the light condition, the degree of light attenuation produced by the filters was 0, 1.0, 2.0, and 3.0 log units. Although all four intensities were presented under each condition, only the intensity data obtained with filters 0 and 1.0 were later used in data analysis.

Phase II consisted of four sessions, containing four trials each, wherein S was exposed to the larger-sized stimulus (a 4° spot of light). Each session lasted from 45 minutes to 1 hour. The previously described stimulus parameters were again manipulated during presentation of this larger stimulus. Because the apparent brightness of the larger stimulus was greater than that of the smaller stimulus for a given physical intensity setting of the photostimulator and

Kodak Wratten filters, the physical settings had to be altered to effect a match in apparent brightness. A brightness match was obtained with the 0 and 1.0 filter conditions used during Phase I by setting the photostimulator at I = 16 and I = 2 with 0 filter attenuation during the dark condition and 0.5 filter attenuation during the light. This effected a match with the filter and intensity settings respectively used during the Phase I light condition.

Table 1 indicates the order of presenting experimental conditions for subjects and main effects in each experimental phase. Both Phase I and II contained four sessions and each session contained a block of four runs. During Phase I, retinal location was varied across runs within each session, and counterbalanced across sessions. Background level was held constant within each session and varied across sessions in counterbalanced order. Flash intensity was varied within each run, and counterbalanced across four-run blocks by means of a Latin square. The small-sized stimulus was presented throughout all runs in Phase I.

Phase II consisted of four sessions, background level being held constant within each session and counterbalanced over the four sessions. Three subjects received the light background condition during the first session and the dark background condition during the second. The background conditions were presented in the opposite order during the third and fourth sessions. The other three subjects received the

Table 1

Experimental Conditions

Phase I: 1° Spot of Light

Site	Background	Intensity			
Foveal	Light	0.5	1.5	0.0	1.0
Foveal	Light	1.5	1.0	0.5	0.0
Peripheral	Light	0.0	0.5	1.0	1.5
Peripheral	Light	1.0	0.0	1.5	0.5
Peripheral	Dark	2.0	0.0	3.0	1.0
Peripheral	Dark	0.0	1.0	2.0	3.0
Foveal	Dark	1.0	3.0	0.0	2.0
Foveal	Dark	3.0	2.0	1.0	0.0
Peripheral	Dark	3.0	2.0	1.0	0.0
Foveal	Dark	2.0	0.0	3.0	1.0
Peripheral	Dark	1.0	3.0	0.0	2.0
Foveal	Dark	0.0	1.0	2.0	3.0
Foveal	Light	0.0	0.5	1.0	1.5
Peripheral	Light	0.5	1.5	0.0	1.0
Foveal	Light	1.0	0.0	1.5	0.5
Peripheral	Light	1.5	1.0	0.5	0.0

Phase II: 4° Spot of Light

Peripheral	Dark	2	16	16	2
Foveal	Dark	2	16	16	2
Foveal	Dark	16	2	2	16
Peripheral	Dark	16	2	2	16
Foveal	Light	2	16	16	2
Peripheral	Light	2	16	16	2
Peripheral	Light	16	2	2	16
Foveal	Light	16	2	2	16
Foveal	Light	2	16	16	2
Peripheral	Light	2	16	16	2
Peripheral	Light	16	2	2	16
Foveal	Light	16	2	2	16
Peripheral	Dark	2	16	16	2
Foveal	Dark	2	16	16	2
Foveal	Dark	16	2	2	16
Peripheral	Dark	16	2	2	16

dark background condition during the first session and the light background condition during the second. The conditions were presented in the opposite order during sessions three and four. Retinal location was balanced across sessions and across each block of four runs. It was held constant within each run. During both Phase I and II, each subject served as his own control.

By use of Wratten filters, a 1 log unit difference in brightness was established between bright and dim flashes in both Phase I and II. Under the dark background condition, the dimmest flash was 2 log units above threshold and the brightest flash 3 log units above. Under the light background condition the dimmest flash was 0.5 log units above threshold, and the brightest flash 1.5 log units above. The log units established were relative to the light background of 10 mL., and to a dark background of less than 0.01 mL.

Recording Apparatus

A Model 7 Grass Polygraph was used for amplification and monitoring purposes throughout recording. The evoked cortical potential was obtained by summating an amplified signal from a Grass 7P5 amplifier with a Mnemotron 400B Computer of Average Transients. Analysis time was set at 0.5 sec., with a gain set at $10^{3.5}$. Calibration procedures indicated that a 1-uv. signal generated an averaged response of 9 mm. A permanent printout was obtained from a Moseley X-Y Plotter, Model 2D-2, with coordinates set at Y = 20 and X = 5.

Commercial 8-mm. silver disc and silver clip electrodes were used for recording and reference.

A Grason-Stadler Model 901-B noise generator served to block out noise associated with the experiment as well as any extraneous noise. To safeguard against electrical noise in recording, the subject was placed in a copper-screened, electrically shielded cubicle.

Stimulating Apparatus

Flashes were generated from a Grass PS2 Photostimulator. Flash rate was regulated by a photoelectric programmer. In essence, the programmer consisted of a tape loop of 45-mm. transparent film on which strips of black tape had been placed. These tape strips, when passed over a photoelectric cell, served to activate circuits, causing flashes to occur. These flashes were produced irregularly with an average inter-stimulus interval of 3 sec.

The stimulus flash was viewed by the subject from the concave side of an opaque white hemisphere which the subject faced from within the cubicle. The distance from the stimulus site to the subject's eye remained approximately 40 cm. throughout the experiment.

For the small stimulus condition, light flashes generated by the photostimulator, after passing through a Kodak Wratten filter, were transmitted to the stimulus site by a tubular light guide (fibre optic). The tip of the light guide was passed through an aperture of the opaque hemisphere and

mounted flush against a translucent screen constructed of white plastic tape. Viewed from the other side, the subject saw a small spot of light of the appropriate diameter each time a flash occurred. For the large stimulus condition, light passed directly from the photostimulator through an aperture of the opaque hemisphere onto the rear surface of a translucent paper screen of the appropriate diameter.

Preparation of the Subject

The naive Ss were subjected to an introductory familiarization with the laboratory, the experiment, and the equipment. The dark adaptation process for all subjects was initiated by having the subject wear red goggles for at least 0.5 hr. Dark adaptation was completed by having the subject remain in total darkness without goggles for another 10-15 min. before recording began. Recordings were obtained monopolarly with a disc electrode placed 2.5 cm. above and to the right of the inion. A reference electrode was placed on the right earlobe. Commercial electrode jelly was used to reduce resistance below 10,000 ohms, as measured with a standard ohmmeter. The disc electrode was held in place by an adjustable elastic headband, the ear electrode held in place by means of a clip. Leads from these electrodes were connected to an output terminal, situated to the left of and behind the subject's head, within the cubicle, which in turn was connected to the input of a 7P5 preamplifier.

Procedure

Prior to recording under the dark condition, the subject became dark-adapted by the method described, but no lengthy preparation of this sort was necessary for the light condition. Electrodes were then attached to the scalp and ear and resistance was checked. Before actual data collection began, the subject sat in the shielded room for a few minutes in order to adjust to the cubicle and to the recording procedure. During this time there was further opportunity for dark adaptation or the appropriate level of light adaptation to occur, depending on the condition being run.

The subject's task was to fixate binocularly in either of two ways: foveally at the center of the hemisphere; or peripherally at a dimly illuminated point 25° to the left of the stimulus. This procedure was used to manipulate the site of retinal stimulation, i.e., foveal versus peripheral. The subject was requested to count the flashes to assure attention. Fatigue effects were controlled by frequent breaks between trials. During Phase I only one recording session was permitted per morning or afternoon. The short duration of Phase II allowed for two recording sessions per morning or afternoon without undue fatigue.

RESULTS

Evoked cortical potential amplitudes were calculated for each subject by measuring the peak-to-trough (and trough-to-peak) distance of three major deflections. These are identified by numbers 1, 2, and 3 in the top left set of tracings of each figure (Figures 1 through 6). The first of these appeared between 90 and 120 msec., illustrated in the raw data as a negative (upward) deflection. This is followed by a positive deflection (downward) which terminates at approximately 180-200 msec. The third deflection was negative and had a latency of 225-250 msec. These three amplitude measurements were summed and the averages taken. Thus there were 16 averaged measures for each of the six subjects, one for each experimental condition, making a total of 96 scores upon which an analysis of variance was performed (Table 2).

The analysis of variance was performed to ascertain whether there were any significant main effects and/or interactions. This analysis is summarized in Table 3. The mean squares which were used as error terms for each of the main effects and interactions are identified in the table, under the column labelled "E.T.", by the appropriate number.

Figures 1 through 6 show the individual evoked potentials obtained for the six subjects during stimulation under each of the four experimental conditions: background, retinal location (site), intensity, and size. Superimposed tracings constitute replications. It can be observed that a given

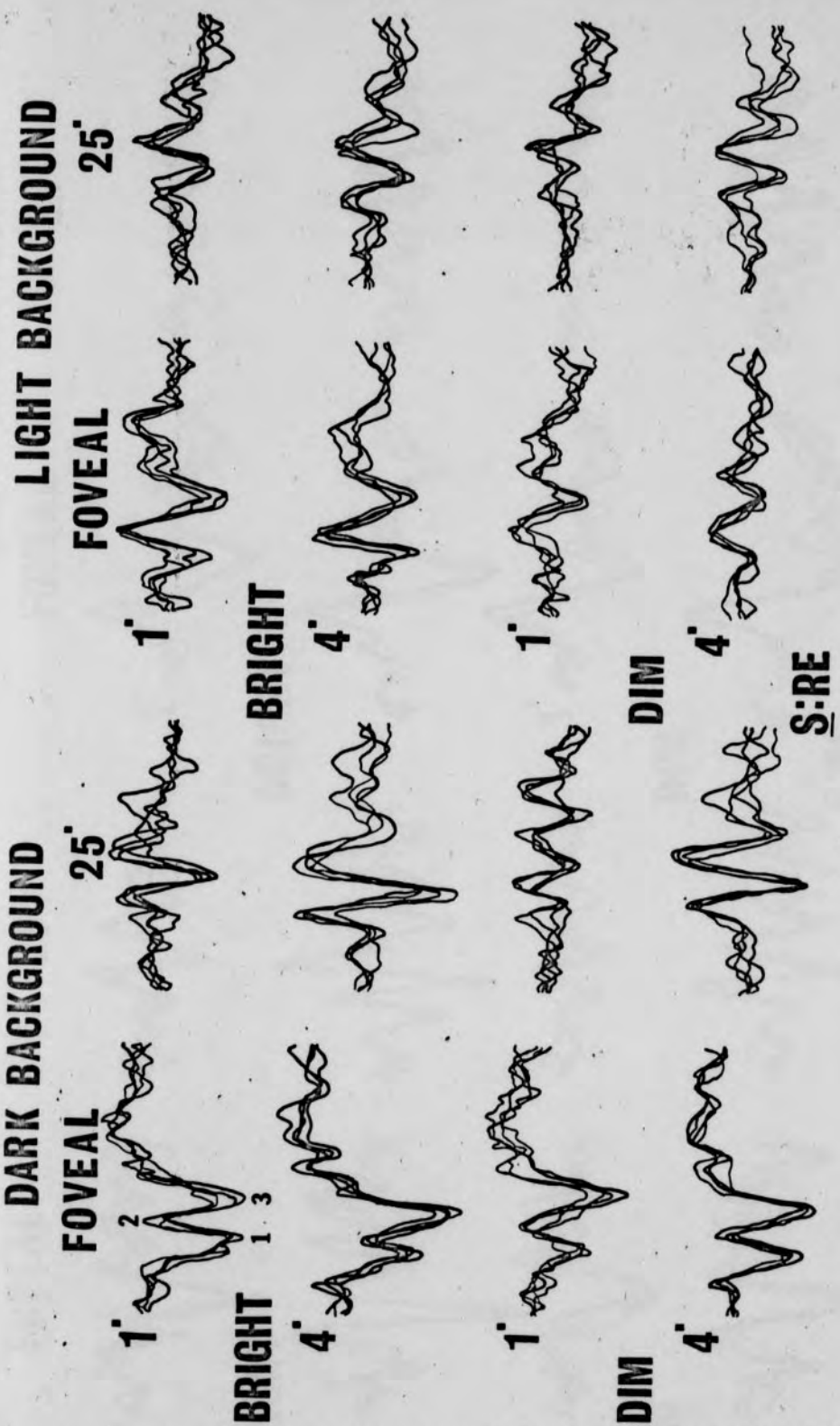

Figure 1. Amplitude of Averaged Evoked Responses Obtained In Each Experimental Condition, Both Phase I and Phase II, for S RE.

Figure 2. Amplitude of Averaged Evoked Responses Obtained in Each Experimental Condition, Both Phase I and Phase II, for S RH

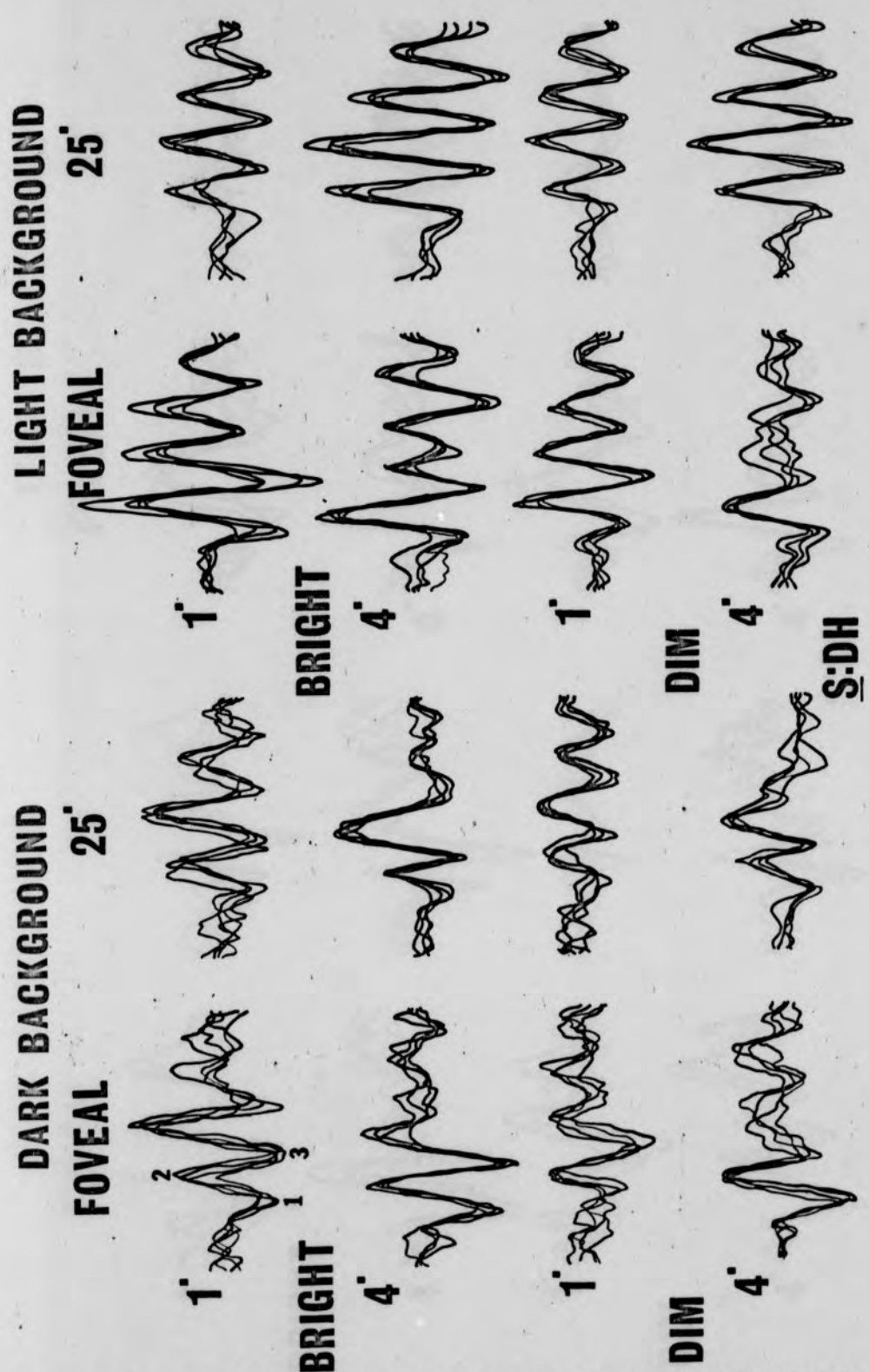

Figure 3. Amplitude of Averaged Evoked Responses Obtained in Each Experimental Condition, Both Phase I and Phase II, for S DH

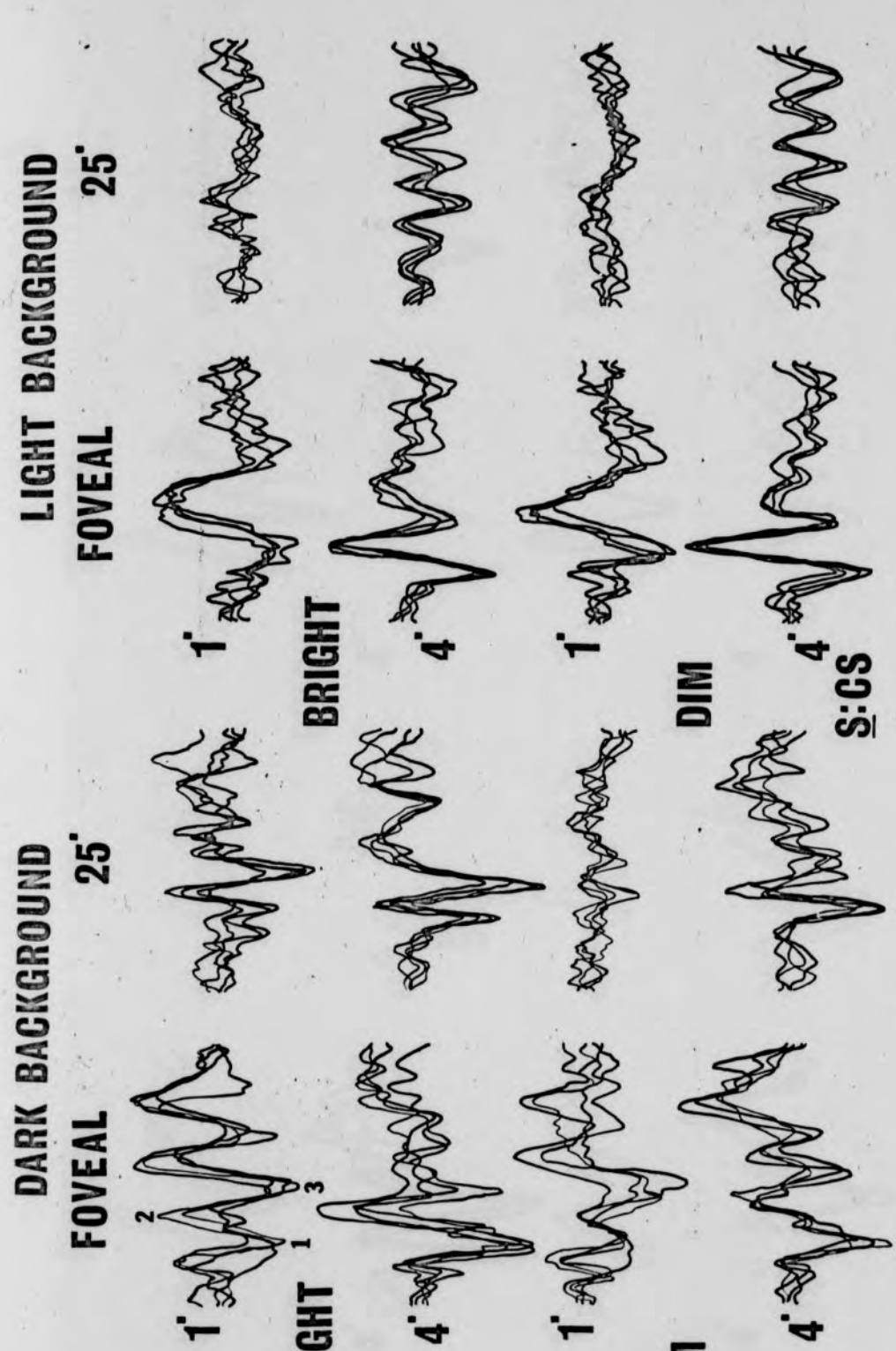

Figure 4. Amplitude of Averaged Evoked Responses Obtained In Each Experimental Condition, Both Phase I and ~~Phase II, for S~~ CS

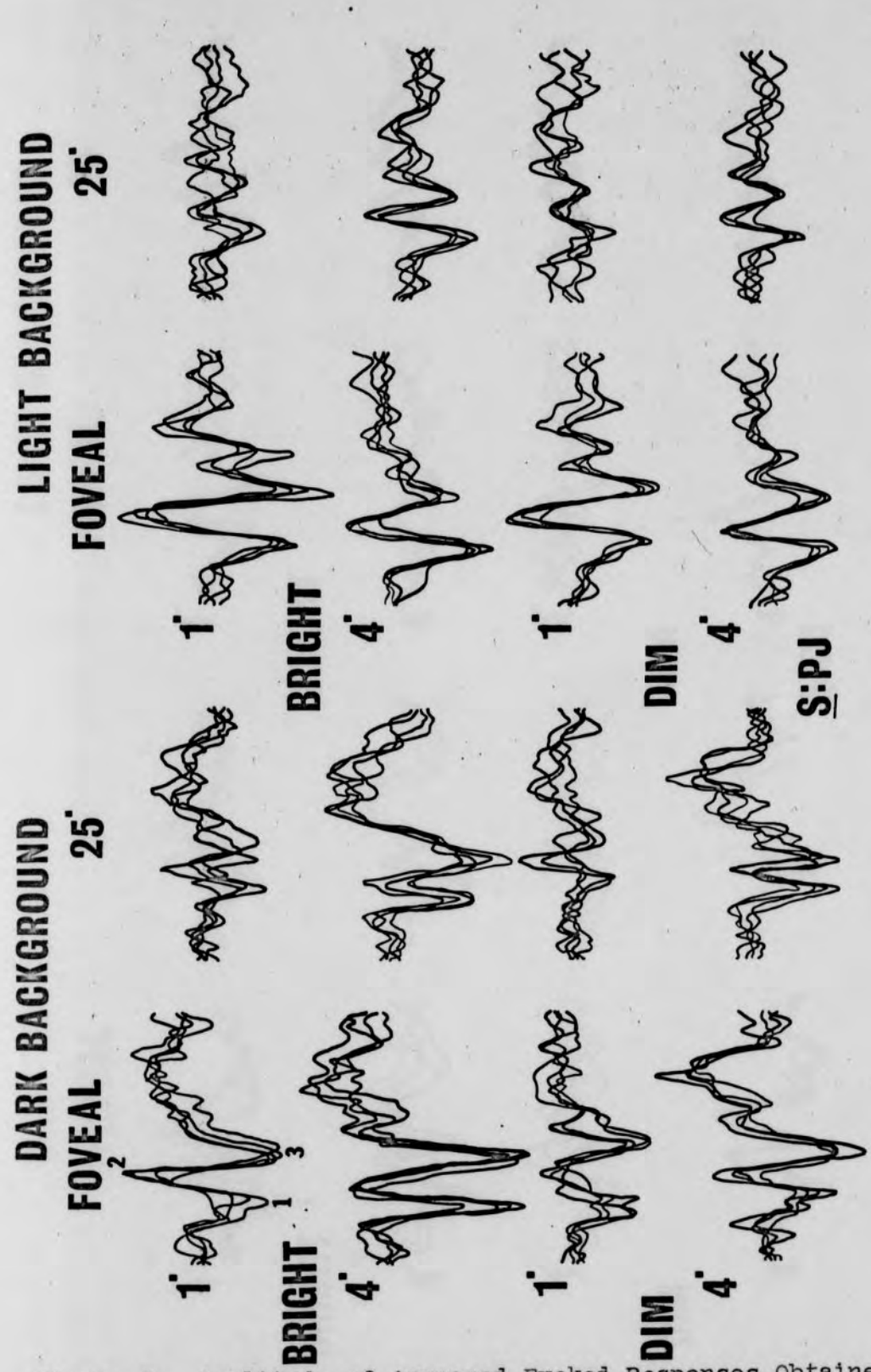

Figure 5. Amplitude of Averaged Evoked Responses Obtained in Each Experimental Condition, Both Phase I and Phase II, for S PJ

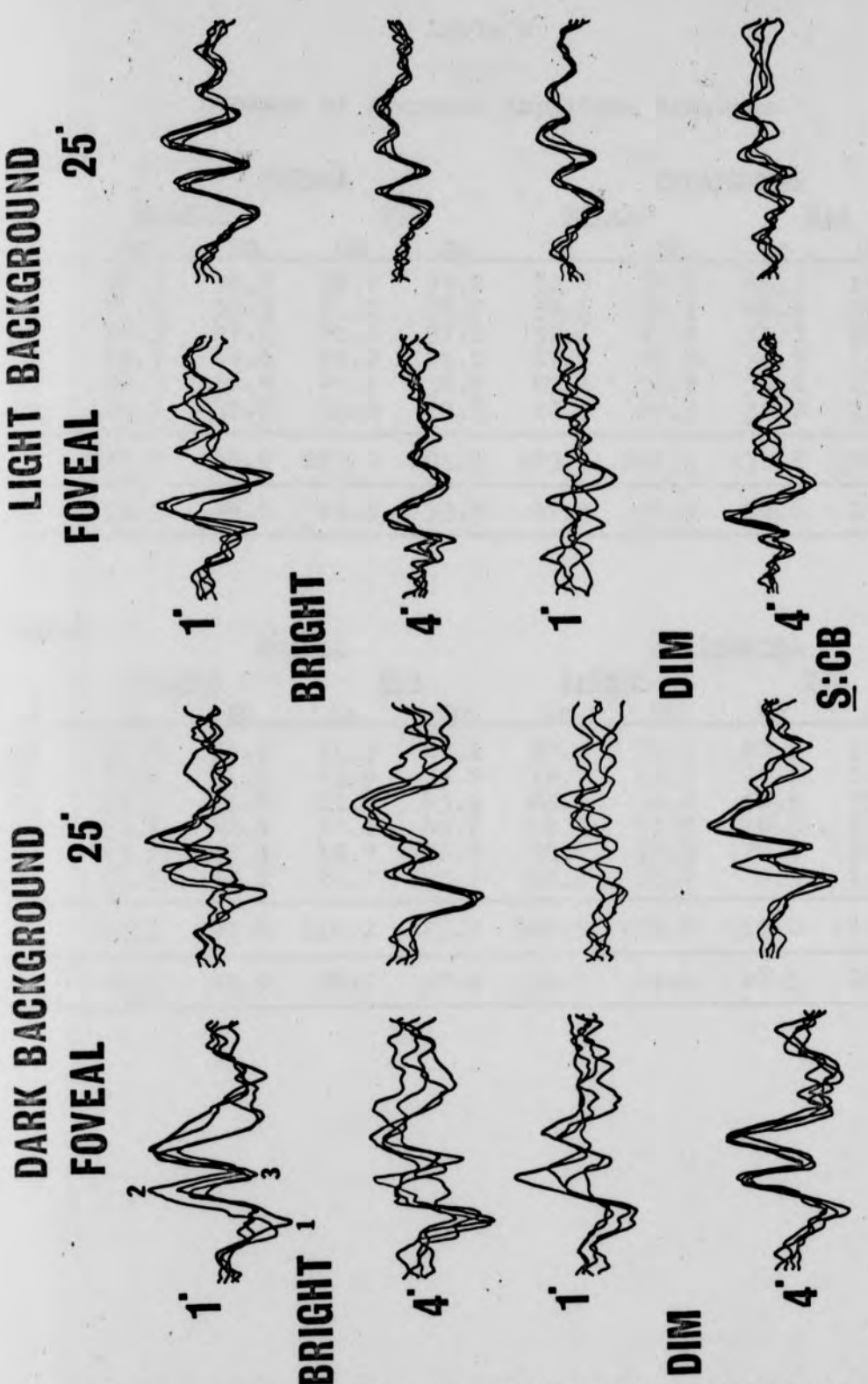

Figure 6. Amplitude of Averaged Evoked Responses Obtained in Each Experimental Condition, Both Phase I and Phase II, for S CB

Table 2

Summary of Averaged Amplitude Measures

Dark:

	Foveal				Peripheral			
	Bright		Dim		Bright		Dim	
S	Lg	Sm	Lg	Sm	Lg	Sm	Lg	Sm
RE	40.3	38.2	37.9	34.0	50.8	30.8	42.3	18.3
RH	75.1	39.5	61.0	37.7	58.5	36.3	48.5	22.3
DH	59.3	47.6	41.4	37.2	37.6	43.2	33.3	25.3
CS	49.9	44.6	45.2	29.7	61.7	28.2	39.3	15.5
PJ	78.3	56.4	49.7	38.9	47.2	36.8	36.6	27.9
CB	30.2	37.7	37.8	23.6	27.5	24.8	31.8	19.3
T	331.1	264.0	273.0	201.1	283.3	200.1	231.8	128.6
$\bar{X}$	55.5	44.0	45.5	33.5	47.2	33.3	38.6	21.4

Light:

	Foveal				Peripheral			
	Bright		Dim		Bright		Dim	
S	Lg	Sm	Lg	Sm	Lg	Sm	Lg	Sm
RE	34.8	34.8	21.3	23.1	23.9	22.6	20.6	13.1
RH	50.8	41.1	41.9	35.2	19.7	14.3	23.2	12.7
DH	58.3	71.4	29.6	45.9	65.6	35.4	58.9	33.7
CS	53.5	42.0	58.0	49.2	19.5	11.3	20.9	12.6
PJ	43.2	67.9	40.7	56.4	38.6	19.3	26.1	19.6
CB	21.5	42.2	24.7	15.7	19.2	23.8	9.3	19.8
T	262.1	299.4	216.2	225.5	186.5	126.7	159.0	111.5
$\bar{X}$	43.7	49.9	36.0	37.6	31.1	21.1	26.5	18.6

Table 3

Analysis of Variance (Amplitude)

Source	SS	DF	MS	ET	F
I. Between Columns	10701.88	15			
A. Background	1121.35	1	1121.35	IIIA	3.47
B. Site	4359.16	1	4359.16	IIIB	18.32**
C. Intensity	1738.25	1	1738.25	IIIC	33.60**
D. Size	1568.97	1	1568.97	IIID	8.84*
A x B	384.40	1	384.40	Pool	5.60*
A x C	72.63	1	72.72	"	1.06
A x D	740.93	1	740.93	"	10.82**
B x C	61.92	1	61.92	"	0.90
B x D	413.76	1	413.76	"	6.03*
C x D	15.44	1	15.44		--
Residual	225.07	5	45.01		--
II. Between Rows	4418.38	5			
III. Rows x Columns	7722.54	75			
A. Ss x Background	1613.31	5	322.66	"	4.70**
B. Ss x Site	1189.71	5	237.94	"	3.47**
C. Ss x Intensity	258.64	5	51.73	"	0.75
D. Ss x Size	887.88	5	117.58	"	2.59*
Ss x A x B	761.88	5	152.38	IIIE	2.39
Ss x A x C	438.67	5	87.73	"	1.37
Ss x A x D	260.29	5	52.06	"	0.82
Ss x B x C	212.73	5	42.55	"	0.67
Ss x B x D	300.53	5	60.11	"	0.94
Ss x C x D	202.36	5	40.47	"	0.63
E. Residual	1596.54	25	63.86		--
Pooled	3773.00	55	68.60		--
Total	22842.80	95			

**p < .01
*p < .05

subject's evoked potential appears highly reliable over replications.

Main Effects

The analysis of variance revealed that the amplitude of the evoked potential varied significantly as a function of the site of stimulation ($p < .01$), the intensity of the stimulus ($p < .01$), and the size of the stimulus ($p < .05$). The background variable was not found to be significant.

The findings revealed by the analysis of variance are clearly defined in Figure 7. Regarding site of stimulation, it may be noted that during both dark and light conditions the amplitude of the foveal response was consistently of greater magnitude than that of the peripheral response. With respect to stimulus intensity, amplitude measures of the bright stimulus (designated as circles) were consistently larger than those of the dim (designated as squares) under both background conditions. Regarding size, the amplitude of the evoked potential to a large stimulus was greater than to a small under all conditions, except during foveal stimulation with a light background level. Despite this exception, the overall effect was significant. Although the graph suggests otherwise, there was no statistically significant difference in overall amplitude between dark and light conditions.

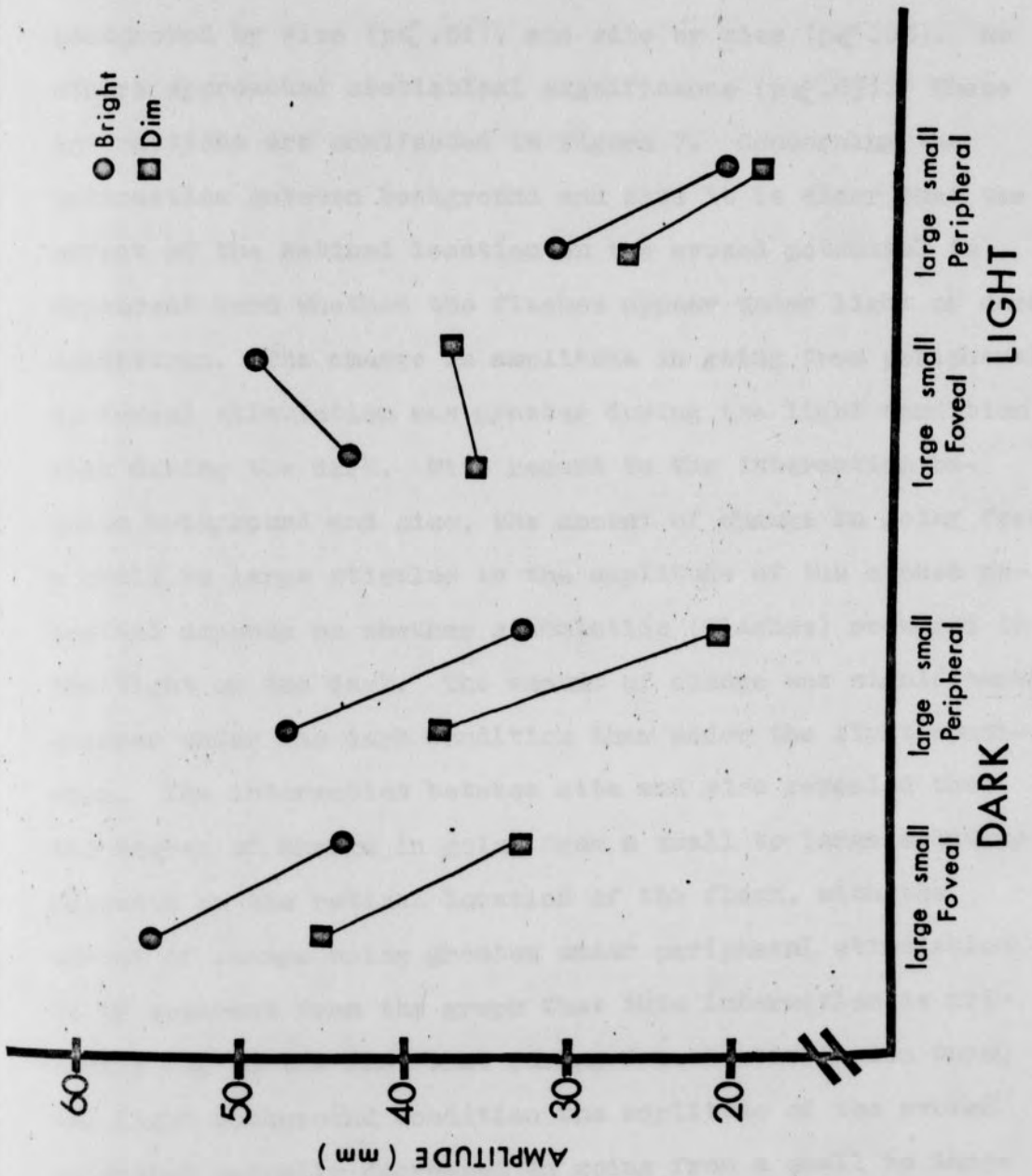

Figure 7. Averaged Amplitude of Evoked Potential Deflections 1, 2, and 3 Obtained Under All Experimental Conditions for All Subjects

Interaction Effects

The analysis of variance revealed three significant first-order interactions: background by site ($p < .05$), background by size ($p < .01$), and site by size ($p < .05$). No others approached statistical significance ($p < .05$). These interactions are manifested in Figure 7. Concerning the interaction between background and site it is clear that the effect of the retinal location on the evoked potential is dependent upon whether the flashes appear under light or dark conditions. The change in amplitude in going from peripheral to foveal stimulation was greater during the light condition than during the dark. With regard to the interaction between background and size, the amount of change in going from a small to large stimulus in the amplitude of the evoked potential depends on whether stimulation (flashes) occurred in the light or the dark. The amount of change was significantly greater under the dark condition than under the light condition. The interaction between site and size revealed that the degree of change in going from a small to large stimulus depended on the retinal location of the flash, with the amount of change being greater under peripheral stimulation. It is apparent from the graph that this interaction is primarily due to the fact that during foveal stimulation under the light background condition the amplitude of the evoked potential actually decreased in going from a small to large target, in contrast to the marked increase that occurred

under all the other conditions.

Several significant interactions existed between Ss and three of the experimental variables: background, site, and size. These interactions merely reflect the fact that the effect of background, site, and size are more pronounced for some subjects than for others.

DISCUSSION

The results yielded by this investigation are similar to those obtained in previous studies concerning visually evoked cortical potentials in relation to background illumination, site of retinal stimulation, stimulus intensity, and stimulus size. These stimulus parameters will be discussed individually in terms of the results of both this and previous investigations.

Intensity Effects

In accord with reported earlier findings, the amplitude of the evoked potential was found to vary systematically with changes in stimulus intensity (Cobb & Dawson, 1960; Creutzfeldt & Kuhnt, 1967; Dill *et al.*, 1968; Perry & Childers, 1969; Vanzulli *et al.*, 1960; and Wicke *et al.*, 1964). The amplitude of the evoked potential increased with increased luminance, that is, the bright stimulus consistently gave larger responses than the dim.

In terms of each separate experimental condition, the decrease in amplitude in cases of high intensity stimulation reported by some investigators (Dill *et al.*, 1968; Montagu, 1967; Perry & Childers, 1969; and Tepas & Armington, 1962) was not found under the stimulus conditions of this experiment. This discrepancy could be interpreted as a result of the relatively low level luminance used in this study. A one log unit difference was established between bright and dim

flashes, with the bright flash, at most, three log units above threshold. There was a tendency, although not statistically significant ($p < .05$), for dim, foveal flashes under a dark background condition to be of greater amplitude than responses under bright peripheral stimulation in a light condition. This tendency could suggest an inhibitory mechanism as proposed by the above authors, though not within the context of the present study.

The amplitude data as a function of intensity lead to a conclusion in agreement with investigators (Eason, Groves, White, & Oden, 1967; Vanzulli et al., 1960; and White & Eason, 1966) that the rise in amplitude and appearance of shorter latency components with increases in intensity indicates that in the presence of intense stimuli the brain receives information in a larger amount and shorter time than in the presence of low intensity stimulation.

Effect of Retinal Locus of Stimulation

Analysis of the amplitude data as a function of the site of retinal stimulation (foveal or peripheral) supports previous findings that visual sensitivity measures drop in magnitude as the retina is stimulated more peripherally DeVoe et al., 1968; Eason et al., 1967a; Eason & Dudley (1971); and Pirenne, 1967). During both light and dark adaptation of the retina, the amplitude of the foveal response was consistently greater than that of the peripheral. This supports proposals (Armington, 1966; Perry & Copenhaver,

1966) that the visual response, although reflecting both photopic and scotopic activity, is essentially dominated by the photopic system.

In conclusion, the site data support the statement by Eason and Dudley (1971) that because of the greater convergence of receptor elements in the periphery of the retina on the bipolar cells, it would be expected that when peripherally-presented stimuli are varied in size, areal summation effects would be greatest. The results are also in accord with the discussion on the Stiles-Crawford effect by investigators (DeVoe et al., 1968; Perry & Childers, 1969; and Pirenne, 1967), based on the proposal that in a gross way, the evoked response decrement with peripheral stimulation follows the receptor density distribution of the retina.

Size Effects

The relationship between stimulus size and the magnitude of the evoked response reflected an inverse relation between the size of the retinal image and intensity required to evoke a response. In agreement with the findings of Graham et al. (1939) and DeVoe et al. (1968), the amplitude systematically followed an increase in size. The overall effect was statistically significant, despite the exception during foveal stimulation with a light background level. Eason and Dudley (1971) report that, as stimulus size increased, the amplitude of the evoked response remained essentially constant for foveally-centered stimulation, but for

peripheral stimulation there was an initial increase in amplitude followed by a progressive decrease. The increase in amplitude of the initial deflection with increasing stimulus size was presumed to parallel the increase in amplitude exhibited by the optic nerve activity. The increase-decrease relation during peripheral stimulation was not evidenced in this study, and it is assumed to be a function of larger diameter stimuli, as well as more peripheral sites of regard.

Within the confines of this investigation, it is concluded that the greater amplitudes evoked by increasing stimulus size are due to a larger informational input to the brain than occurs during stimulation with small-sized stimuli.

Background Effects

Background effects (under light and dark adaptation) were not found to be statistically significant, despite an apparent tendency for responses under dark adaptation to be generally of greater magnitude than under light. This tendency suggests the photopic nature of the visually evoked response, and, although the overall effect is not significant, lends support to Hecht (1921) in the proposal that the dark-adapted retina increases in sensitivity.

The lack of significance found in the background effect is considered to be a function of the particular threshold conditions of the present experiment. The log unit difference that existed between bright and dim flashes possibly

provided too minimal a difference to exact a significant effect.

Interaction Effects

As stated in the introduction, the interaction effects of the four independent variables on the evoked response are of special interest, since the majority of research done previously did not deal with such interactions. Few studies have dealt systematically with more than one stimulus variable, and those which did, often ignored the possibility of interaction effects. The significant interactions found in the present study point to a need to deal with all of these variables in a given experiment, even though some may be held constant.

Site was found to interact significantly with size, i.e., the amount of change in moving from small to large stimuli was greater under peripheral stimulation. This interaction was due to the amplitude of the evoked potential in fact decreasing during foveal stimulation under the light background condition, in moving from a small to large stimulus; this being in contrast to the increase under the other conditions. This is suggestive of the proposal advanced by Boynton and Riggs (1951) in hypothesizing that the effect of increasing either stimulus area or intensity, within the limits of their experiment, was to increase the illumination of the vast "nonfocal" area. It was their conclusion that it was this nonfocal areal illumination which produced nearly all of the

evoked response.

Statistically significant interactions were also found between background and site, and background and size. The greater change in moving from peripheral to foveal stimulation during the light background condition, as compared to the dark, is in accord with anatomical studies dealing with the photopic and scotopic mechanisms of the retina (LeGrand, 1957). The greater magnitude of the visual response in moving from a small to large stimulus in the dark condition than in the light, is in accord with results reported by Boynton (1968). The background interactions of site and size are related both to the increased sensitivity of the retina during background conditions and to the increase in size of the summation area under these conditions.

Summary

In general, these findings provide basic parametric data which should prove useful for future investigations in vision research. More specifically the data indicate the importance of being aware of the interaction effects among the variables manipulated. These findings should be helpful in determining the stimulus values to use for evoking a maximal cortical response when behavioral variables are being manipulated. Recent research dealing with reaction time (Eason & Dudley, 1971) and pattern vision (Harter & Suitt, 1970), for example, lend themselves readily to the use of these findings.

In summary, there is a systematic effect on the visually evoked response to changes in stimulus size, stimulus intensity, and site of retinal stimulation under dark and light background conditions. The visually evoked cortical potential provides to the investigator a useful tool for obtaining knowledge of the human eye, as well as of the activity of the visual system in general.

Further research into the effect and interaction of these stimulus parameters, as well as physical parameters, is certainly in order. The tendencies and suggestive findings provided by this study deserve further and more exacting manipulation to determine a working knowledge as to the neurological-anatomical basis of vision and the evoked cortical potential.

BIBLIOGRAPHY

Armington, J. C. Spectral sensitivity of simultaneous electroretinograms and occipital responses. In Clinical Electroretinography, Supplement to Vision Research, 1966, 225-233.

Artseulova, O. K. & Ivanitskii, A. M. Zavisimost' mezhdu komponentami vyzvannogo otveta i fonovi electroentsefalogrammoi u cheloveka. (Dependence between the components of the evoked response and background electroencephalogram in man.) Zhurnal Vysshei Nervnoi Deyatel' nosti, 1967, 17(4), 677-680.

Barlow, J. S. & Ciganek, L. Lambda responses in relation to visual evoked responses in man. Electroencephalography and Clinical Neurophysiology, 1969, 26, 183-192.

Bartlett, N. R., Eason, R. G., & White, C. T. Binocular summation in the evoked cortical potential. Perception and Psychophysics, 1968, 3(1B), 75-76.

Bartlett, N. R. & White, C. T. Evoked potentials and correlated judgments of brightness as functions of interflash interval. Science, 1965, 148(3672), 980-981.

Boynton, R. M. The psychophysics of vision. In R. N. Haber (Ed.), Contemporary theory and research in visual perception. New York: Holt, Rinehart & Winston, 1968.

Boynton, R. M. & Riggs, L. A. The effect of stimulus area and intensity upon the human retinal response. Journal of Experimental Psychology, 1951, 42(4), 217-226.

Buchsbaum, M. & Silverman, J. Stimulus intensity control and the cortical evoked response. Psychosomatic Medicine, 1968, 30(1), 12-22.

Chang, H.-T. The evoked potentials. In J. Field, H. W. Magoun, & V. E. Hall (Eds.), Handbook of physiology. Section I: Neurophysiology. Washington, D. C.: American Physiological Society, 1959. Pp. 299-313.

Ciganek, L. The EEG response (evoked potential) to light stimulus in man. Electroencephalography and Clinical Neurophysiology, 1961, 13, 165-171.

Ciganek, L. Variability of the human visual evoked potential: normative data. Electroencephalography and Clinical Neurophysiology, 1969, 27, 35-42.

Cobb, W. A. & Dawson, G. D. The latency and form in man of the occipital potentials evoked by bright flashes. Journal of Physiology, 1960, 152, 108-121.

Copenhaver, R. M. & Beinhocker, G. D. Evoked occipital potentials recorded from scalp electrodes in response to focal visual illumination. Investigations in Ophthalmology, 1963, 2(4), 393-406. (a)

Copenhaver, R. M. & Beinhocker, G. D. Objective visual field testing: occipital potentials evoked from small visual stimuli. Journal of the American Medical Association, 1963, 186, 767-772. (b)

Copenhaver, R. M., Beinhocker, G. D., & Perry, N. W. Jr. Visual evoked retinal and occipital potentials. Documents in Ophthalmology, 1964, 18, 473-482.

Creutzfeldt, O. D. & Kuhnt, U. The visual evoked potential: physiological, developmental and clinical aspects. In The evoked potentials, Supplement to Electrophysiology and Clinical Neurophysiology, 1967, No. 26. Pp. 29-41.

Dawson, G. D. A summation technique for the detection of small evoked potentials. Electroencephalography and Clinical Neurophysiology, 1954, 6, 65-84.

Dawson, W. W., Perry, N. W. Jr., & Childers, D. G. Flash and scan stimulation of retinal fields and evoked response production. Electroencephalography and Clinical Neurophysiology, 1968, 24, 467-473.

DeVoe, R. G., Ripps, H., & Vaughan, H. G. Jr. Cortical responses to stimulation of the human fovea. Vision Research, 1968, 8, 135-147.

Dill, R. C., Vallecalle, E., & Verzeano, M. Evoked potentials, neuronal activity and stimulus intensity in the visual system. Physiology and Behavior, 1968, 3(5), 797-801.

Dustman, R. E. & Beck, E. C. Long term stability of visually evoked potentials in man. Science, 1963, 142, 1480-1481.

Eason, R. G. & Dudley, L. M. Effect of stimulus size and retinal locus of stimulation on visually evoked cortical potentials and reaction time in man. 1971 (in press).

Eason, R. G., Groves, P., White, C. T., & Oden, D. Evoked cortical potentials: relation to visual field and handedness. Science, 1967, 156, 1643-1646. (a)

Eason, R. G., Oden, D., & White, C. T. Visually evoked cortical potentials and reaction time in relation to site of retinal stimulation. Electroencephalography and Clinical Neurophysiology, 1967, 22, 313-324. (b)

Eason, R. G. & White, C. T. Averaged occipital responses to stimulation of sites in the nasal and temporal halves of the retina. Psychonomic Science, 1967, 7(9), 309-310.

Fessard, A. Brain potentials and rhythms. In J. Field, H. W. Magoun, & V. E. Hall (Eds.), Handbook of physiology. Sectoin I: Neurophysiology. Washington, D. C. American Physiological Society, 1959. Pp. 299-313.

Gastaut, H., Regis, H., Lyagoubi, S., Mano, T., & Simon, L. Comparison of the potentials recorded from the occipital, temporal and central regions of the human scalp, evoked by visual, auditory and somato-sensory stimuli. In The evoked potentials, Supplement to Electrophysiology and Clinical Neurophysiology, 1967, No. 26, Pp. 19-28.

Graham, C. H., Brown, R. H., & Mote, F. A. The relation of size of stimulus and intensity in the human eye: I. Intensity thresholds for white light. Journal of Experimental Psychology, 1939, 24(6), 555-573.

Granit, R. Receptors and sensory perception. New Haven: Yale University Press, 1955.

Harter, R. M. & Suitt, C. D. Visually-evoked cortical responses in pattern vision in the infant: a longitudinal study. Psychonomic Science, 1970, 18, 235-237.

Hecht, S. The nature of foveal dark adaptation. Journal of General Physiology, 1921, 4, 113-141.

Jonkman, E. J. The average cortical response to photic stimulation. Amsterdam: 1967.

Katzman, R. The validity of the visual evoked response in man. In H. E. Whipple & R. Katzman (Eds.), Sensory evoked response in man. In Annals of the New York Academy of Science, 1964, 112.

Kitajima, H. On the cerebral evoked response in man as a function of the intensity of flicker stimuli. Electroencephalography and Clinical Neurophysiology, 1967, 22, 325-336.

Kopell, B. S., Wittner, W. K., & Warrick, C. L. The effects of stimulus differences, light intensity, and selective attention on the amplitude of the visual averaged evoked potential in man. Electroencephalography and Clinical Neurophysiology, 1969, 26, 619-622.

LeGrand, Y. Light, colour, and vision. London: Chapman & Hall, 1957.

LeGrand, Y. Form and space vision (rev. ed.). Indiana University Press, 1967.

Montagu, J. D. The relationship between the intensity of repetitive photic stimulation and the cerebral response. Electroencephalography and Clnical Neurophysiology, 1967, 23, 152-161.

Perry, N. W. & Childers, D. G. The human visual evoked response: method and theory. Springfield, Illinois: Charles C Thomas, 1969.

Perry, N. W. & Copenhaver, R. M. Evoked retinal and occipital potentials during dark adaptation in man. In Clinical Electroretinography, supplement to Vision Research, 1966. Pp. 249-254.

Pirenne, M. H. Vision and the eye. London: Chapman & Hall, 1967.

Shagass, C. & Schwartz, M. Evoked cortical potentials and sensation in man. Journal of Neuropsychiatry, 1961, 2, 262-270.

Tepas, D. I. & Armington, J. C. Properties of evoked visual potentials. Vision Research, 1962, 2, 449-461.

Tweel, L. H. van der & Spekreijse, H. "Visual evoked responses:" the clinical value of electroretinography. ISCERG Symposium, Ghent, 1966.

Vanzulli, A., Bogacz, J., Handler, P., & Garcia-Austt, E. Evoked responses in man: I. Photic responses. Acta Neurologica Latinoamerica, 1960, 6, 219-231.

Vaughan, H. G. Jr. The perceptual and physiologic significance of visual evoked responses recorded from the scalp in man. In Clinical Electroretinography, supplement to Vision Research, 1966.

Vaughan, H. G. Jr. & Hull, R. C. Functional relation between stimulus intensity and photically evoked cerebral responses in man. Nature, 1965, 206, 720-722.

Walter, W. G. The analysis, synthesis and identification of evoked responses and contingent negative variation (CNV). Electroencephalography and Clinical Neurophysiology, 1967, 23, 486-490.

Werre, P. F. & Smith, C. J. Variability of responses evoked by flashes in man. Electroencephalography and Clinical Neurophysiology, 1964, 17, 644-652.

Whipple, H. E. & Katzman, R. (Eds.) Sensory evoked response in man. Annals of the New York Academy of Science, 1964, 112.

White, C. T. & Eason, R. G. Evoked cortical potentials in relation to certain aspects of visual perception. Psychological Monographs, 1966, 80 (Whole No. 632).

Wicke, J. D., Donchin, E., & Lindsley, D. B. Visual evoked potentials as a function of flash luminance and duration. Science, 1964, 146, 83-85.